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Causes and Consequences of Open Space Conservation in U.S. Urban Areas

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Abstract: The large variation in the share of land for open space across U.S. urban areas raises some interesting questions: a) what determines the amount of open space in an urban area? b) How does open space affect community characteristics such as housing prices and local property tax rates? and c) are existing amounts of open space across U.S. urban areas socially optimal? In this paper, we conduct theoretical and empirical analysis to address these issues. Our theoretical analysis reveals that price elasticities of housing demand and supply, economies of scale in providing public services, and values of environmental benefits from open space are key parameters affecting the optimal amount of open space in an urban area. Our empirical results confirm that the price elasticity of housing supply varies widely across U.S. urban areas and is a significant determinant of the amount of open space in an urban area. Urban areas with a larger share of land in open space tend to have lower property tax rates and lower per-capita spending on public services. A significant share of U.S. urban areas are found to have too little open space in the sense that even if additional open space would not provide any amenities, it would still increase total land values and social welfare. However, for more than 10% of U.S. urban areas, the total value of environmental benefits from open space must be at least as large as the total land value to justify for the amount of open space they have. Some of these urban areas likely have too much open space.

Keywords: Open space conservation; land values; environmental amenities

JEL Classification: H4; R3; Q2

This paper is based on work supported by OECD Environment Directorate under SRM #: PO500030787. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of their home institutions, or the OECD Environment Directorate. We thank Valentine Rinner and Winston Oakley for their assistance with data collection.

1. Introduction

Growing recognition of the economic and environmental benefits from open space has sparked waves of conservation initiatives at local and state levels in the United States and around the world. From 1998 to 2014, U.S. voters approved 1861 conservation initiatives in local and state referenda, providing more than $72 billion for open space conservation (The Trust for Public Land, 2015). The implementation of locally based, long-term open-space conservation plans has been touted as a "smart growth" strategy in the United States (U.S. Environmental Protection Agency, 2015). In Europe, although there are a number of policy approaches, specific to each country, open space conservation has been acknowledged as an important aspect of the European Union's strategy for the urban environment (Commission of the European Communities, 2004), and the European Landscape Convention is a Europe-wide instrument that deals specifically with open space conservation (Déjeant-Pons, 2006).

Open space includes all unbuilt, working and natural lands within urban, suburban, and rural areas. It comprises both public lands such as city parks and stream corridors, and private lands such as forests, rangelands, and grasslands. In this paper, we focus on open space conservation in urban areas. Urban open space provides many economic benefits (USDA Forest Service, 2007). For example, urban forests cool urban heat islands, moderates local climate, reduces energy costs, and enhances property values (Stone et al., 2015; USDA Forest Service, 2014; Donovan and Butry 2010, 2011). In many instances it is less expensive to conserve open space that naturally maintains water quality than to construct costly-engineered facilities for water filtration and other treatments (State of New York Office of the State Comptroller, 2010). Open space also provides many environmental benefits and ecosystem services. For example, native grasslands reduce water runoffs, protect water quality, and provide wildlife habitat. Urban forests and green space filter air and provide shelter to wild animals (USDA Forest Service, 2014). Open space also provides many socioeconomic benefits. For example, urban green space provides places for people to socialize and play, reducing stress from work and urban life (Ulrich, 1993, 1984). More canopy cover in urban areas is associated with higher birth weights (Donovan et al., 2011), and lower crime rates (Donovan and Prestemon, 2012). As urban areas expand, both the importance of the benefits from urban open space and the challenges to their conservation will increase (USDA Forest Service, 2011).

There is a large variation in the share of land for open space across U.S. urban areas (see the maps in the data section). This raises some natural questions: What determines the amount of open space in an urban area? How does open space affect community characteristics such as housing prices and local property taxes? and c) Are existing amounts of open space across U.S. urban areas socially optimal? In this paper, we attempt to address these questions. Specifically, we first develop a theoretical model to identify the key factors affecting the optimal amount of open space in an urban area. From the model, we derive the necessary and sufficient conditions for open space conservation to increase a) the property tax rate, b) the level of public services, c) total land values within the city, and d) social welfare. We then conduct an empirical analysis to test whether the key factors identified in the theoretical model are indeed important and to examine how open space area affects property tax rates and local public services, using a comprehensive database we compiled for 1656 urban areas in the United States. Finally, we assess whether the existing amount of open space in each urban area in our sample is socially optimal, using parameter values estimated in this study and those found in the literature.

Our theoretical analysis reveals that price elasticities of housing demand and supply, economies of scale in providing public services, and values of environmental benefits from open space are key parameters affecting the optimal amount of open space in an urban area. Our empirical results confirm that the price elasticity of housing supply varies widely across U.S. urban areas and is a significant determinant of the amount of open space in an urban area. Urban areas with a larger share of land in open space tend to have lower property tax rates and lower per-capita spending on public services. A significant share of U.S. urban areas are found to have too little open space in the sense that even if additional open space would not provide any amenities, it would still increase total land values and social welfare. However, for more than 10% of U.S. urban areas, the total value of environmental benefits from open space must be at least as large as the total land value to justify for the amount of open space they have. Some of these urban areas likely have too much open space.

In the next section, we briefly review the literature on open space conservation. In section 3, we present a theoretical model to identify the key factors influencing the optimal amount of open space in an urban area. Section 4 discusses the empirical models and estimation methods. Section 5 describes the data used in the analysis. Section 6 discusses the empirical results. Section 7 concludes.

2. The Literature

Many hedonic studies have evaluated the effect of open space on nearby property values (e.g., Irwin and Bockstael, 2001; Irwin, 2002; Geoghegan, 2002; Geoghegan et al., 2003; Anderson and West, 2006; Acharya and Bennett, 2001). An important finding of these studies is that the value of proximity to open space is affected by the nature and type of open space (e.g., public vs. private open space) and neighborhood characteristics (e.g., income, crime, density). This paper complements previous hedonic studies by examining the effect of open space conservation on *total* property values within an urban area, rather than focusing on its effect on *nearby* property values.

A few studies have examined the welfare effect of open space conservation. Walsh (2007) develops an equilibrium framework to analyze the impact of open space protection and urban growth control policies on the entire metropolitan landscape and finds that different strategies for open space conservation can have markedly different landscape and welfare implications. Klaiber and Phaneuf (2010) examine how open space amenities affect residential location choices in the Twin Cities area of Minnesota using a horizontal sorting model and find that heterogeneity across types of open space and across households is a critical determinant of the welfare impacts of open space conservation.

Several studies have examined the effect of open space conservation on urban landscapes. Wu and Plantinga (2003) examine the effect of open space policy on urban development patterns and find that open space designation can lead to more development as well as leapfrog development (i.e., development that skips over vacant land to build in a remote location). Wu (2006) examines the effect of natural and social amenities on urban landscapes and find that to a large extent, urban development patterns and community characteristics are determined by spatial heterogeneity in amenities. Wu (2014) develops a theoretical model to analyze the fiscal and land value impacts of public open-space conservation in a budget-constrained city, and finds that open space conservation is more likely to increase total land values and municipal services in metropolitan areas that have stringent land use regulations, high development densities, and relatively little open space. The present paper builds upon Wu (2014), but extends it to include environmental benefits from open space. In addition, we conduct an empirical analysis to identify the key factors that determine the amount of open space in U.S. urban areas and to evaluate whether existing amounts of open space across U.S. urban areas are socially optimal.

3. The Theoretical Model

Consider open space conservation in an urban area. The local government is assumed to choose the amount of open space to maximize social welfare (*SW*), which include both economic and environmental benefits capitalized into the land values and those that are not. The values of economic and environmental benefits from open space are measured by people's willingness to pay for open space. Polinsky and Shavell (1976) shows that in an open urban area where there is free migration and where the local government can take the prevailing national utility as exogenous, the total willingness to pay for open space amenities equals the change in aggregate land values. To model the capitalization of open space amenities into land values, we extend Poterba's framework of real property values (Poterba, 1991) to include open space amenities and municipal services. According to Poterba's framework, equilibrium in a real property market requires that the return on real property investments such as on a piece of land for residential development equals the user cost of ownership: $r/P= c_0$, where P is the land price, r is the rental value of housing services, the ratio, r/P, represents the return on the investment, and c_0 is the user cost of ownership, which includes the local property tax rate and the mortgage interest rate. The equilibrium condition can also be written as: $P= r/c_0$, which states that the value of land for residential development equals the present value of the stream of housing services provided by the land, discounted at the rate of user cost of ownership. Expanding this condition to include the capitalization of municipal services and open-space amenities, the value of land for residential development in an urban area, P, can be written as:

$$P = \frac{r(S)g^{\mu}}{\tau + c}, \qquad (1)$$

where

S = the amount of open space in the urban area,

$r(S)$ = rental value of housing services from the land,

g = the level of municipal services such as city water and sewer

μ = elasticity of land value with respect to municipal services

τ = the property tax rate

c = other components of the user cost of ownership (e.g., mortgage interest rate, maintenance cost).

The rental value of housing services $r(S)$ is determined by the demand and supply of housing services. The demand for housing services, $H^d(r,S)$, depends on the rent r and the amount of open space in the urban area S. Open space provides amenities, which attract households into the urban area and encourage additional development. However, when too much land is vacant, fragmentation may become a dis-amenity and discourages development. Thus, $H^d(r,S)$ can increase or decrease with S. The demand for housing is also affected by household income Y and total population N (Potepan 1996), but we suppress these variables to emphasize the role of open-space amenities. The supply of housing services, $H^s(r,S)$, can be written as $H^s(r,S) = h^s(r)[A(S)-S]$, where $h^s(r)$ is the level of housing services provided per unit of land and increases with rent, and $A(S)$ is the total urban area, including urban open space. Open space removes land from the path of bulldozers, but encourages development by providing amenities. This suggests that $A(S)$ can increase or decrease with S (We and Plantinga, 2003). Formally, $r(S)$ is defined by $H^d(r,S) = H^s(r,S)$. Differentiating this equation with respect to S gives:

$$\frac{dr}{dS} = \frac{r}{S(A-S)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d})}\left[S(1-A'(S)] + (A-S)\varepsilon_S^{H^d}\right] \tag{2}$$

where $\varepsilon_r^{H^d} = \frac{\partial H^d}{\partial r}\frac{r}{H^d} < 0$, $\varepsilon_r^{H^s} = \frac{\partial H^s}{\partial r}\frac{r}{H^s} > 0$, and $\varepsilon_S^{H^d} = \frac{\partial H^d}{\partial S}\frac{S}{H^d}$, which can be positive or negative depending on whether the amenity or fragmentation effect dominates.

Equation (2) indicates that the more inelastic the housing supply and demand are, the larger the effect of open space on residential land rent. However, the effect can be positive or negative. If $A'(S)$<1 and $\varepsilon_S^{H^d} > 0$, open space conservation increases the housing rent because it reduces the total housing supply and increases the total housing demand. On the other hand, If $A'(S)$>1 and $\varepsilon_S^{H^d} < 0$, open space conservation reduces the housing rent because it increases the total housing supply, and reduces the total housing demand.

Assume all land except open space is assessed for taxes. The total property tax revenue, T, for the city is

$$T = \tau[A(S) - S]P = \frac{\tau[A(S) - S]r(S, a(S))g^{\mu}}{\tau + c}. \tag{2}$$

The city's annualized cost of open-space conservation is

$$C^s = cSP = \frac{cSr(S, a(S))g^{\mu}}{\tau + c}. \tag{4}$$

Equation (4) indicates that the cost of open-space conservation, the level of municipal services, and the property tax rate are all simultaneously determined. The cost of municipal services is assumed to be:

$$C^g = g(A - S)^{\lambda}, \tag{5}$$

where $\lambda \in [0,1]$ is a parameter indicating the economy of scale in the provision of municipal services, with $\lambda = 1$ indicating no economy of scale and $\lambda = 0$ indicating the largest economy of scale, with all municipal services being pure non-rival public goods.

The local government chooses the property tax rate, the level of municipal services and the amount of open space to maximize social welfare:

$$\underset{(\tau,g,S)}{Max} \quad SW = A(S)[P(\tau, g, S) - P_0] + B(S) + (T - C^s - C^g), \tag{7}$$

$$s.t., \quad C^s + C^g \leq T, \tag{8}$$

where P_0 is the land price without public services and open space conservation, thus the first term in (7) represents the total willingness to pay for open space and public services; the second term represents the economic and environmental benefits of open space that are not capitalized into the property values, and the last term represents the government surplus, which equals zero when the government's budget is in balance.

From the first-order conditions of the maximization problem, we can derive:

$$\tau^* = \frac{c}{1-\mu}\left(\mu + \frac{S}{A(S) - S}\right), \tag{9}$$

$$g^* = \left[\frac{\mu r(S, a(S))}{(A(S) - S)^{\lambda - 1}}\right]^{\frac{1}{1-\mu}}, \tag{10}$$

Substituing (9) and (10) into (7) and the total land value equation and differentiating the resulting expressions, as well as (9) and (10), with respect S, we obtain:

$$\frac{d\tau^*}{dS} > 0 \;\; iff \;\; \varepsilon_S^A < 1, \tag{11a}$$

$$\frac{dg^*}{dS} > 0 \;\; iff \;\; (\varepsilon_S^A - s)\left[(1-\lambda)(\varepsilon_r^{H^s} + \varepsilon_r^{H^d}) - 1\right] + (1-s)\varepsilon_S^{H^d} > 0, \tag{11b}$$

$$\frac{dTLV}{dS} \geq 0 \;\; iff \;\; (\varepsilon_S^A - s)\left[(1-\lambda\mu)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1\right] + (1-s)\varepsilon_S^{H^d} \geq 0 \tag{11c}$$

$$\frac{dSW}{dS} \geq 0 \;\; iff \;\; (\varepsilon_S^A - s)[(1-\lambda\mu)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1] +$$

$$(1-s)[\varepsilon_S^{H^d} + \nu(\varepsilon_r^{H^s} - \varepsilon_r^{H^d})] \geq 0, \tag{11d}$$

where s=$S/A(S)$ is the share of open space in the urban area, and $\nu = \frac{S \cdot \frac{dB}{dS}}{TLV}$ is the value of environmental benefits from open space relative to the total land value.

Several results follow directly from (11a)-(11d). First, equation (11a) states that open space increases the property tax rate if and only if the percent of developed land within the urban area decreases with open space conservation (i.e., $\varepsilon_S^A < 1$). Intuitively, when $\varepsilon_S^A < 1$, open space conservation reduces the share of land paying for property taxes and thus leads to increases in the property tax rate. On the other hand, when $\varepsilon_S^A > 1$, open space conservation increases the tax base as a percent of the total urban area, which leads to a reduced property tax rate.

Second, open space conservation can also increase or decrease the level of municipal services. When $\varepsilon_S^A < s$, open-space conservation reduces the total developed area within the city, which will lead to an increase in the level of municipal services if the demand and supply of housing services are sufficiently price inelastic and if open space does not generate disamenities. By reducing the supply of developable land, open-space conservation increases the rental value of housing services and hence the marginal benefit of municipal services, leading to more municipal services. When $\varepsilon_S^A > s$, open-space conservation increases the total developed area within the city and the level of municipal services if the demand and supply of housing services are sufficiently price elastic and if open space does not generate disamenities. In this case, open space conservation increases the total developed area, but does not significantly reduce the land rent, and thus will increase the total land value and the marginal benefit of municipal services, which also leads to an increase in the level of municipal services.

Third, open-space conservation increase the total land value, even if it generates no amenities, if it reduces total developed area (i.e., $\varepsilon_S^A < s$) and the demand and supply of housing services are sufficiently price inelastic. In this case, land scarcity created by open space conservation leads to increases in land prices and thus the total value. On the other hand, open-space conservation reduces the total land value if it leads to more development and if the demand and supply of housing services are sufficiently price elastic.

Forth, the effect of open-space conservation on total land values depends on the amount of land preserved. When little open space exists in the city, some land conservation will likely increase the total land value when the demand and supply of housing services are sufficiently price inelastic because both conditions $\varepsilon_S^{H^d} > 0$ and $\varepsilon_S^A > s$ likely hold at low levels of open space. However, as more land is preserved, it will eventually reduce the total land value when the demand and supply of housing services are sufficiently price inelastic because both conditions $\varepsilon_S^{H^d} < 0$ and $\varepsilon_S^A < s$ likely hold at high levels of open space.

Fifth, the effect of open-space conservation on total land value depends on local characteristics. In small cities surrounded by rural land, extra open space may not generate additional amenities or land scarcity because there are close substitutes for new open space and developable land and the demand and supply of housing are likely to be price elastic. Open-space conservation in such cities will likely reduce total land value. In contrast, in large cities with high development densities, stringent regulatory environments, and inelastic demand and supply of housing, large parcels of new open space tend to provide a high level of amenities and create additional land scarcity. In those cities, open-space conservation tends to increase total land value.

Finally, from (11d), we can derive the optimal share of open space in the urban area:

$$s^* = \frac{\varepsilon_S^{H^d} + [(1-\lambda\mu)\varepsilon_S^A + \nu](\varepsilon_r^{H^s} + \varepsilon_r^{H^d}) - \varepsilon_S^A}{\varepsilon_S^{H^d} + [(1-\lambda\mu) + \nu](\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1}. \tag{12}$$

By setting $\nu = 0$ in (12), we obtain the share of open space that maximizing the total land value within the urban area. Note that equation (12) only implicitly defines the optimal share of open space because some of the parameters (i.e., the housing demand elasticity) may be affected by the amount of open space in the urban area. Nevertheless, we can use it to to evaluate how changes in parameter values (e.g., a decrease in the price elasticity of housing demand due to income growth) on the optimal share of open space. Suppose it is not socially optimal to preserve all land for open space. Then $\frac{dSW}{ds}$<0 at s=1, and s^*<1. From (11d), $(1-\varepsilon_S^A)[1-(1-\lambda\mu)(\varepsilon_r^{H^s}-\varepsilon_r^{H^d})]<0$. Using this condition, we can prove the following:

$$\frac{\partial s^*}{\partial \varepsilon_S^{H^d}} \geq 0\ , \tag{13a}$$

$$\frac{\partial s^*}{\partial \nu} \geq 0, \tag{13b}$$

$$\frac{\partial s^*}{\partial \varepsilon_r^{H^s}} \geq 0 \text{ iff } (1-\varepsilon_S^A)[(1-\lambda\mu)\left(\varepsilon_S^{H^d}+\varepsilon_S^A\right)+\nu] > 0, \tag{13c}$$

$$\frac{\partial s^*}{\partial \varepsilon_r^{H^d}} \geq 0 \text{ iff } (1-\varepsilon_S^A)\left[(1-\lambda\mu)\left(\varepsilon_S^{H^d}+\varepsilon_S^A\right)+\nu\right] < 0. \tag{13d}$$

Although the optimal amount of open space always increases with $\varepsilon_S^{H^d}$ and ν, it can increase or decrease with the price elasticities of housing demand and supply (i.e., $\varepsilon_r^{H^s}$, $\varepsilon_r^{H^d}$). Specifically, the optimal amount of open space increases with the price elasticity of housing supply and decreases with the price elasticity of housing demand if $0<\varepsilon_S^A<1$ and $\varepsilon_S^{H^d}>0$. In this case, open space conservation increases housing demand and reduces percent of land developed within the urban area, leading to an increase in land values. The effect on housing values is smaller when housing supply and demand are more elastic, leading to a larger optimal share of land for open space.

4. Empirical Approaches

The purpose of the empirical analysis is two-fold. First, we want to test if the key variables identified in the theoretical model are indeed statistically significant. Second, we would like to examine whether existing amounts of open space across U.S. urban areas are socially optimal. The methods for achieving each of the objective are discussed below.

4.1. Testing the empirical significance of the key parameters

To verify if the key variables identified in the theoretical model are indeed significant empirically, we estimate the following simultaneous equation system:

$$\tau_{it}^{*} = \alpha_{0i} + \alpha_1 s_{it}^{*} + \alpha_2 A_{it} + \alpha_3 c_{it} + \boldsymbol{\alpha_4 X_{it}} + e_{it}^{\tau}, \quad (14a)$$

$$g_{it}^{*} = \beta_{0i} + \beta_2 s_{it}^{*} + \beta_2 A_{it} + \beta_3 c_{it} + \beta_4 r_{it} + \boldsymbol{\beta_5 Y_{it}} + e_{it}^{g}, \quad (14b)$$

$$s_{it}^{*} = \gamma_{0i} + \gamma_1 \varepsilon_{Sit}^{H^d} + \gamma_2 \varepsilon_{rit}^{H^d} + \gamma_3 \varepsilon_{rit}^{H^S} + \gamma_4 \varepsilon_{Sit}^{A} + \boldsymbol{\gamma_5 Z_{it}} + e_{it}^{s}, \quad (14c)$$

where *i* is an index of study units (see the discussion in the data section), *t* year, $\alpha's, \beta's,$ and $\gamma's$ are parameters to be estimated; the *e's* are error terms. This equation system is specified based on equations (9), (10), and (12). Alternatively, one can estimate a system of reduced-form equations of the property tax rate, the level of municipal services, and the share of open space. The simultaneous approach allows us to examine how local property tax rates and public services are related to open space share, while the reduced-form models are easier to estimate. We report results from both approaches in the paper.

As shown by equation (9), in addition to the amount of open space, parameter μ, which reflects household preferences and willingness to pay for public services, also affects the property tax rate. We include a vector of variables, $\boldsymbol{X_{it}}$, in (14a) to try to capture the effect of parameter μ on the property tax rate. Two approaches could be used to select variables for $\boldsymbol{X_{it}}$. One is to assume that μ does not change much over time, and its effect is captured by the study unit-specific fixed effect α_{0i}. Under this approach, we do not include any variables in $\boldsymbol{X_{it}}$ (specification 1). Alternatively, one could try to identify time-varying variables that affect μ and include those variables in $\boldsymbol{X_{it}}$ (specification 2). Income, education, and age are commonly believed to affect preferences and willingness to pay for goods and services and thus could be included in $\boldsymbol{X_{it}}$ in specification 2.

Similarly, two approaches could be used to select variables for $\boldsymbol{Y_{it}}$ to reflect the effect of λ and μ on municipal services, resulting in two different specifications. One is to assume that λ and μ do not not change much overtime and their effects are captured by the study unit-specific fixed effect β_{0i}. Thus, no variable would be included in $\boldsymbol{Y_{it}}$ under this approach. Alternatively, one could try to include time-varying variables that may affect λ and μ. λ measures the degree of rivalry in municipal services and may be affected by variables such as total population, total developed area, and patterns of urban development. Thus, in addition to including income, education, and age, one could include total population, total developed area, and the degree of fragmentation in $\boldsymbol{Y_{it}}$.

Two approaches can also be used to select variables for $\boldsymbol{Z_{it}}$ to reflect the effect of $\lambda, \mu,$ and υ on open space conservation. One is to include truly exogenous variables that affect $\lambda, \mu,$ and υ. Alternatively, one could include all proxy variables for λ and μ (i.e., $\boldsymbol{Y_{it}}$), as well as variables affecting the environmental benefits from open space, including variables reflecting the existing land use and land use patterns such as the degree of fragmentation in the urban area.

Although the second specification allows us to examine how income, education, age, water area, and other demographic and topographic features may be correlated with open space conservation and local public finance, it would likely suffer endogeneity problems. With open space conservation, some high-income households may be attracted to the community. Thus, variables such as income, education, and total population are likely to be simultaneously determined with the open space area, the property tax rate, and the level of public services. When these potentially endogenous variables are included in the model, it could lead to biased estimates. Thus, we adopt the first specification in our empirical analysis and include only variables that we believe are truly exogenous in $\boldsymbol{X_{it}}$, $\boldsymbol{Y_{it}}$, and $\boldsymbol{Z_{it}}$.

The equation system (11a)-(11c) is recursive in that the open space share s_{it}^* appears in the property tax rate equation (11a) and the level of municipal service equation (11b), but the property tax rate τ_{it}^* and the level of municipal services g_{it}^* do not appear in the open space share equation. Both equations (11a) and (11b) are overly identified, and the equation system is estimated using a three-stage least square (3SLS). Because we use estimated values of elasticities for each unit i, this reduces potential endogeneious concerns about elasticity variables in the equation ststem.

4.2. Examing if existing amounts of open space are optimal

Using equation (11c) and the parameter values that we estimated or found in the literature, we can evaluate if increasing open space conservation will increase total land value within an urban area. If the necessary and sufficient condition in (11c) hold, we can see that increasing open space conservation will increase total land values within the urban area. It would also increase social welfare as long as additional open space does not generate disamenities (i.e., iff $\nu \geq 0$). However, if $(\varepsilon_S^A - s)\left[(1-\lambda\mu)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1\right] + (1-s)\varepsilon_S^{H^d} < 0$, then reducing the amount of open space in the urban area will increase the total land value within the urban area, which means local residents are sacrificing or relinquishing some land values for open space. This sacrifice can be justified if some of the environmental benefits from open space are not capitalized into the land values. We can calculate the implied value of environmental benefits from open space as a percent of total land value (i.e., ν) from equation (12) by assuming that the existing amount of open space is socially optimal. For example, if the implied value of ν equals one, it means that the value of non-capitalized environmental benefits from open space must be at least as large as the total land value to justify the amount of open space in the urban area. If people's willingness to pay for the non-capitalized environmental benefits is smaller (larger) than the total land value, then we can conclude that the urban area has too much (little) open space.

5. Data

We compile a panel dataset covering 1,656 Urban Areas (UAs) in the U.S. We use the U.S. Census Bureau delineation to define Urban Areas. Although we have detailed land-use data for each UA for three years (2001, 2006, 2011), most of the other data are available only at the Core Based Statistical Area (CBSA) level. CBSAs are geographic entities delineated by the U.S. Office of Management and Budget (OMB) for use by Federal statistical agencies in collecting, tabulating, and publishing Federal statistics. CBSAs comprised of two statistical areas: Metropolitan Statistical Area (MSA) and Micropolitan Statistical Area (µSA). A MSA contains a core urban area of 50,000 or more population, and a µSA contains an urban core of at least 10,000 (but less than 50,000) population. Therefore, all data are aggregated to the CBSA level for econometric analysis. Figure 1 maps out the 1,656 UAs (the green areas) and their corresponding CBSAs. Some CBSAs do not include a UA[1]. Boundaries are based on the 2010 Census data as they are the only available ones for our studied period.

[1] Most UAs lie within a single CBSA, however some overlap significantly between multiple CBSAs. Those exceptions need to be addressed in order to lead the empirical investigation and weight dependent variables appropriately. In this analysis, a UA qualifies as overlapping if 25% or more of its surface lies outside its main CBSA (only fragments with at least 20% of the UA within a single CBSA are kept and considered overlaps). For

5.1. Data on open space and other dependent variables

Land use and open space data for UAs are generated using the National Land Cover Database (NLCD), issued by the Multi-Resolution Land Characteristics (MRLC) Consortium (Jin et al. 2013). The NLCD provides the capability to comprehensively assess national land cover changes and trends across the United States from 2001 to 2011. The NLCD provides land cover data at a spatial resolution of 30 meters over 16 land cover classes, based on the Anderson Land Cover Classification System. Four land cover classes (Dwarf scrub, sedge/herbaceous, lichens, and moss) exist only in Alaska, which is excluded from our study because of the short growing season and scarcity of cloud free imagery. The remaining 12 land cover classes and some summary statistics are listed in Table 1.

One of the land cover classes that is particularly relevant to this study is “Developed, Open Space”. It comprises “areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes” (The Multi-Resolution Land Characteristics (MRLC) consortium, 2015). “Developed, Open Space” may include both public open space and private open space. In addition, it may not include all public open space because some public open space may be undeveloped land such as forests or wetlands. Thus, we define two open space variables. The first one is “developed, open space”. The second one is “total open space”, which includes all types of land except low, medium and high intensity development.

Figure 2 shows the amount of developed open space as a percent of total land area in U.S. UAs in 2011. Developed open space includes city parks, golf courses, and vegetation planted for recreation or erosion control. It may also large-lot single-family housing units. From a national perspective, UAs in the Southeast have much more developed open space than any other part of the country. The Northeast and most urban areas on the West Coast and the Great Lake have lower percent of developed open space. Figure 3 shows the percent changes in developed open

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example, considering Beloit (WI-IL), 65% of its surface is in Janesville, WI and 35% in Rockford, IL. There are 40 out of 1656 UAs that overlap.

space from 2001 to 2011 across the UAs. Because the boundaries of the Urban Areas are defined based on the 2010 Census data and are assumed to be fixed during the study period, the total amount of open space decreases in all UAs as more land is converted to development. Most of urban areas gain some developed open space during this period, except for someurban areas in the West Coast, Southern Plains, Florida Coast, and Michigan.

The other two dependent variables in our simultaneous equation system (14a)-(14c) are the property tax rate and the level of municipal services. The property tax rate and the marginal tax rate in the CBSA were both calculated using data from the U.S. Census Public Use Microsamples (PUMA) dataset. Two PUMA's responses were used in the calculation of the property tax rate: the self-reported value of the property, and the self-reported amount of property tax paid. To calculate the marginal tax rate variable, the following PUMA's responses were used: the self-reported household income, state of residence, marital status, and number of children in the household (Oakley, 2014). There are no data that directly measure the level of municipal services. We use the per-capita spending on public services, including public education, public welfare, police protection, natural resources, and parks and recreation to approximate this variable. The county-level, per-capita spending on each item was obtained from U.S. Census of Bureau and was aggregated to the CBSA level.

5.2. Estimating housing demand and supply elasticities

A number of previous studies have estimated price elasticity of housing demand and supply. For example, Green et al. (2005) estimated the supply elasticities by using the definition of elasticity: $\varepsilon = \frac{\%\Delta Q}{\%\Delta P}$, where %ΔQ is the percentage change in housing supply, and %ΔP is the percentage change in housing price. Rearranging the terms of this equation yields: $\%\Delta Q = \varepsilon(\%\Delta P)$. Based on this definition, Green et al. (2005) estimate the supply elasticity for 45 U.S. Metropolitan Statistical Areas, using time series data. Specifically, the regression equation for each MSA is as follows: $\gamma_t = \beta_0 + \beta_1(\rho_{t-1}) + \varepsilon_t$, where β_0 is a constant term, β_1 is estimate of the price elasticity of housing supply, ε is a random error term, γ is the percentage change in the quantity of housing supply, and is calculated by dividing the number of new housing permits issued in the CBSA by the existing housing stock, which is estimated by dividing the total population by the average number of people per household in the U.S. (2.5). ρ represents the percentage change in housing prices in each CBSA. In the regression, the first lag of ρ is used to avoid simultaneity problems.

In this paper, we expand Green et al. (2005) to include the demand side of the market. Specifically, we estimate the following equation system for each CBSA:

$$\gamma_t^S = \beta_0 + \beta_1 \rho_t + \beta_2 \Delta w_t + \beta_3 \Delta c_t + \beta_4 R_t + \varepsilon_t^S, \tag{15a}$$

$$\gamma_t^D = \delta_0 + \delta_1 \rho_t + \delta_2 \Delta I_t + \delta_3 \Delta S_t + \delta_4 \Delta g_t + \delta_5 \Delta F_t + \varepsilon_t^D, \tag{15b}$$

$$\gamma_t^S = \gamma_t^D \tag{15c}$$

where

γ_t^S = the percentage change in the quantity of housing supply,

γ_t^D = the percentage change in the quantity of housing demand,

Δw_t = the percentage change in the average wage rate for construction workers,

Δc_t = the percentage change in timber price,

R_t = the land use regulation index in the CBSA,

ΔI_t = the percentage change in median household income,

ΔS_t = the percentage change in the amount of open space,

Δg_t = the percentage change in per-capita governemtn spending on municipal services,

ΔF_t = the percentage change in the degree of land fragmentation,

$\beta's$ = parameters for the housing supply equation ,

$\delta's$ = parameters for the housing demand equation,

ε_t^S, ε_t^D = the error terms.

The percentage change in the quantity of housing supply and the percent change in housing price are calculated in the same way as in Green et al. (2005). In addition, we expand Green et al. (2005)'s supply equation to include the percentage change in the average wage rate for construction workers and in timber prices to reflect the effect of two most important components of construction costs.

Compared to Green et al. (2005), our approach has at least two advantages. First, it allows us to treat the endogeneity of housing price directly, instead of using lagged prices. Second, it also allows us to estimate the demand elasticity with respect to hosuing price, income, open space area, and per-capita government spending on municipal services. Both the demand

and supply equations are overly identified, and the simultaneous equation system is estimated using a three-stage least square estimator (3SLS).

In addition to estimating $\varepsilon_r^{H^s}$, $\varepsilon_r^{H^d}$, and $\varepsilon_S^{H^d}$ for each CBSA, we also estimate the elasticity of total developed area with respect to open space for each CBSA by regressing total developed area on open space, income and total population using a fixed-effect log-linear model. The coefficient on log(open space) gives the elasticity of total developed area with respect to open space (ε_S^A).

Housing price data are from the Freddie Mac Housing Price Index (FMHPI). The FMHPI is based on repeat transactions on one-family detached and townhome properties serving as collateral on loans originating between January 1, 1975 and the end of the most recent index month (Freddie Mac, 2009).

Data on median housing prices in the CBSAs for 2000, 2005, and 2010 were acquired from the 2010 U.S. Census American Community Survey (ACS) dataset, as was the average commute time (in minutes) for each CBSA. The population level for 2000, 2005 and 2010 were taken from the U.S. Census. Population density, represented by the average population density in the CBSA, was calculated using the total MSA area and population, both taken from U.S. Census data.

Two different indexes were used to measure the stringency of land-use regulation in each MSA. The first index was created by Saks (2008), which listed land-use regulation levels for 83 MSAs. This index was generated using data from six different surveys that asked questions about local land use regulations. The earliest survey was conducted in 1975 and the latest was in 1990. The second index is the Wharton Residential Land Use Regulation Index (WRLURI) created by Gyourko et al. (2008). This index was generated by surveying over 2000 jurisdictions across the U.S. The survey included questions about the regulatory process for housing, the rules for residential land use, and outcomes of the regulatory process (Gyourko et al., 2008). Responses to the surveys were used to generate 10 sub-indices, which Gyourko et al. used in a factor analysis to generate an overall index value for 47 MSAs.

5.3. Data on other parameter values

Other parameter values we need for evaluating the optimal amount of open spave are λ and μ. There is some empirical evidence about parameter λ, representing the economy of scale in providing municipal services. Carruthers and Úlfarsson (2008) analyze local government expenditures in 3075 counties in the continental United States and report an estimate of 0.02 for the elasticity of per-capita direct government expenditure with respect to the percent of land area developed. Hortas-Rico and Solé-Ollé (2010) analyze the effect of urban expansion on local government spending in 2500 municipalities in Spain and find that the elasticity of per-capita spending with respect to urbanized area is 0.05–0.06. Both studies control for population density. Therefore, their results suggest that the value of parameter λ is close to 1, which is consistent with wide-spread findings in the literature that most local government services do not exhibit a significant degree of publicness (Reiter and Weichenrieder, 1997). Thus, we set λ =1.

There is an enduring debate about the capitalization of local fiscal variables into property values (Yinger, 1982). The debate has stimulated many empirical studies, dating back to the seminal article by Oates (1969). But relatively few studies directly estimate elasticity of land value with respect to the level or quality of municipal services (μ). One exception is Potepan (1996), who uses the 1974–1983 Annual Housing Survey data to analyze variation in housing prices, rents, and land prices among 58 U.S. MSAs. Potepan (1996) finds that the quality of public services (measured by the percent of households reporting excellent or good quality of public services) is significant in explaining the variation in land prices, and reports an estimate of 0.68 for the elasticity of land price with respect to the quality of public services. Based on the empirical evidence, we set $\mu = 0.68$ when calculating the s^{vm} for each CBSA.

6. Estimation Results

We first report the econometric results on the key variables that affect open space areas and local public finance, and then focus on the optimal amount of open space.

6.1. Estimated Demand and Supply Elasticities[2]

[2] The demand and supply elasticities reported in table 2 are estimated separately, instead of jointly from a demand-supply equation system, as specified in section 5.3. Specifically, the supply elasticities are estimated by following Green et al. (2005), and the demand elasticities are estimated seperatedly for each CBSA based on using the demand equations: $H_t^d = H(r_t, I_t, S_t, F_t, g_t) + \varepsilon_t$, where H_t^d is Housing demand in year *t,* which equals total housing

Table 2 summarizes the estimated demand and supply elasticities. The mean of the estimated price elasticities of housing demand is -0.92 for the log-linear model and -0.85 for the linear model. The mean of the estimated price elasticities of housing demand is consistent with previous findings that housing demand is price inelastic. For example, Sirmans and Redman (1979) estimate price elasticity of demand for urban residential land ($\varepsilon_r^{H^d}$) in 52 urban areas and report values between -0.68 and -0.32. Hanushek and Quigley (1980) estimate price elasticity of housing demand and report two estimates for Pittsburgh households and two for Phoenix households. The 95% confidence intervals of the two Pittsburgh estimates are (-0.95, -0.33) for the basic model and (-0.54, -0.22) for the expanded model. The corresponding estimates for Phoenix households are (-0.71, -0.20,) and (-0.63, -0.19), respectively. These estimates are smaller than those reported by Polinsky and Ellwood (1977), who estimate price elasticity for new single-family detached housing with 95% confidence intervals of (-0.99, -0.51) and (-0.86, -0.56), respectively. The mean value of the six estimates of the price elasticity of housing demand from the three studies is -0.56.

Table 2 also reports the elasticity of demand with respect to income, open space, and public spending on selected pubic services. Mean income elasticity of demand for housing is estimated to be 0.51 for the log-linear model and 0.42 for the linear model. These mean estimates are within the range of income elasticity of demand for housing reported by previous studies (e.g., the value varies from 0.21 to 0.87 in different studies summarized by Mayo (1981)). However, few previous studies report estimates of housing demand elasticity with respect to open space or public services. Our results indicate that the elasticity of housing demand with respect to open space is positive in about 45% of the 343 CBSAs that are included in the final dataset. For the rest of the CBSAs, the elasticity of housing demand with respect to open space is estimated to be negative. This implies that urban areas in these CBSAs may already have too much open space and additional open space will lead to lower demand for housing. The elasticity of demand for housing with respect to public expenditure is estimated to be 0.63 for the log-

expenditure divided by housing price in year *t*, r_t is housing price in year *t*, F_t is the degree of fragmentation in year *t*, and all other variables are defined as before. Because the estimation does not deal with endogeneity issues, the estimated demand elasticities must be treated as preliminary.

linear model and 0.61 for the linear model, indicate that housing demand increases with municipal public expenditure.

The price elasticities of housing supply are also reported in Table 2. Comparing our housing supply elasticity estimates to Green et al. (2005), our results show improved reliability. Green et al. (2005) provided estimates for only 45 MSAs using data from (1980-1997). We provide supply elasticity estimates for 349 CBSAs using data from 1980-2012. Only 51% of the estimates in Green et al. (2005) were statistically different than zero. 82% of our estimates are statistically significant. This improvement is, due to the increased number of observations for each MSA (18 in Green et al. versus up to 33 in this study). If one compares the 20 estimates that are statistically significant in both studies, the correlation between the two sets of estimates reaches 99%.

6.2. Causes and consequences of open space

We estimate the simultaneous equation system (14a)-(14c) in linear and log-linear functional forms, as shown in Table 3 and Table 4, respectively. For each functional form, we also report results for two alternative ways of constructing the explanatory variables. Thus, we have four models reported in Tables 3 and 4. In Models 1 and 3 the demand elasticities are estimated using the log-linear demand function, while in Models 2 and 4, the demand elasticities are estimated using the linear demand functions. In addition, we have estimated the simultaneous equation system (20a)-(20c) by expanding the explanatory variables to include demographic control variables (income, education, median age, and population). The results are reported in Table A1 and A2 in appendix B. Thus, we have a total of eight models/specifications estimated for the simultaneous equation system (16a)-(16c).

The results are robust across the eight specifications for each equation in the system (open space equation, property tax rate, public spending equation). The coefficient on the price elasticity of supply is positive in the open space equation, while the coefficient on the price elasticity of demand is negative. In addition, the coefficient on the supply elasticity is also statistically significant at the 1% level of significance, indicating that urban areas in CBSAs where housing supply is more price elastic tend to

have more open space. This is encouraging in the sense that both the price elasticities of demand and supply are estimated, regression attenuation biases tend to cause the coefficient estimates to approach zero.

The coefficient on the open space share variable is negative and statistically significant in both the property tax rate and the public expenditure equations, indicating that urban areas in CBSAs with a larger share of land in open space tend to have lower property tax rates and lower levels of public spending on education, public welfare, police protection, natural resources, and parks and recreation. Although the negative effects of property tax rates support some of the arguments of public open space advocates, the negative effect on public expenditure indicates that open space conservation entails opportunity costs in terms of reduced spending on other public services.

In summary, the empirical results confirm our theoretical findings that the elasticities of supply and demand for housing are key variables determining the amount of open space in a UA. Both price elasticities of housing demand and supply vary significantly across U.S. CBSAs. CBSAs with stringent land use regulations and high development densities tend to have lower elasticities of housing supply (Green et al., 2005; Oakley, 2014). Those places tend to have a smaller share of land in open space, higher property tax rates and lower levels of per-capita spending on public services.

6.3. Property-value-maximizing share of open space

Additional open space increases total land values within an urban area, i.e., $\frac{dTLV}{dS}>0$ if and only if (15) holds. By substituting the estimated parameter values for ε_S^A, $\varepsilon_r^{H^s}$, $\varepsilon_r^{H^d}$, and $\varepsilon_S^{H^d}$, $\delta = 0$, $\lambda = 1$, and $\mu = 0.68$ into equation (15), we find that $\frac{dTLV}{dS} > 0$ for 36% of CBSAs. This implies that even if open space conservation does not provide any environmental benefits, it is still warranted in those places as long as it does not generate dis-amenities.

We find that $\frac{dTLV}{dS} < 0$ for 64% of CBSAs. The total land values would be increased if the local government reduces the total amount of open space in the urban areas in those 217 CBSAs. The loss in total land values can be justified only if open space provides sufficient amount of environmental benefits. Specifically, using equation (19), we can calculate the implied value of environmental benefits of open space relative to the total land value υ in those CBSAs by assuming the current amount of open space is optimal. The results are summarized in Table 5.

The mean of the implied values of environmental benefits is 59% of the total land value based on the log-linear demand function and 50% based on the linear demand function.

Figure 4 shows the 50 CBSAs with the highest implies values of environmental benefits relative to the total land value. The implied value of environmental benefits is at least 62% of the total land value. For the top 25 CBSAs, the total value of environmental benefits of open space must be at least as large as the total land value to justify the amount of the open space they have.

7. Conclusions

Growing recognition of the economic and environmental benefits of open space has sparked waves of conservation initiatives at local and state levels in the United States. As communities invest more in open space conservation, it is important to understand its economic and fiscal implications. This paper fills a gap in the literature by investigating theoretically and empirically the key factors that affect the effects of open space conservation on property values and local public finance and by examining the property-value-maximizing and optimal amount of open space in U.S. urban areas.

Several key insights have been gained from this study. First, we found that open space conservation increase the total land value, even if it generates no amenities, if the demand and supply of housing services are sufficiently price inelastic. In this case, the positive effect of open-space conservation on land value due to the reduced land supply outweighs the negative effect of increased property taxes, leading to more municipal services and higher property values. On the other hand, open-space conservation reduces the total land value if it does not generate much amenities and if the demand and supply of housing services are sufficiently price elastic.

Second, the effect of open-space conservation on land value depends on the amount of land preserved - a small amount of open space conservation will likely increase the total land value, while too much open space conservation tends to have the opposite effect.

Third, our empirical results confirm our theoretical findings that the price elasticities of housing supply is indeed significant in determining the amount of open space in U.S. urban areas. Although the demand for housing is quite inelastic in many U.S. urban areas, the supply elasticity varies significantly across U.S. urban areas. U.S. urban areas with less stringent land use regulation and low population densities tend to have higher price elasticities of housing supply. Opportunity costs of open space conservation tend to be low, leading to a larger share of land allocated to open space. In contrast, U.S. urban areas with stringent land use regulation and high population densities tend to have low elasticities of housing supply. Opportunity costs of open space conservation tend to be high, leading to a smaller share of land allocated to open space.

Fourth, we find that urban areas with a larger share of land in open space tend to have lower property tax rates and lower levels of public spending on education, public welfare, police protection, natural resources, and parks and recreation. Although the negative effect on property tax rates supports some of the arguments of public open space advocates, the negative effect on public expenditure indicates that open space conservation entails opportunity costs in terms of reduced spending on other public services.

Finally, we find that the marginal effect of open space on total land values is positive for 36% of Core Based Statistical Areas (CBSA) in our sample. This implies that even if open space conservation does not provide any environmental benefits, more open space is still warranted in those places as long as it does not generate dis-amenities. For the other 64% of CBSAs, the marginal effect of open space on total land values is negative, implying that reducing the amount of open space in those areas would increase the total land value. But open space also provides environmental benefits and ecosystem services, which are not capitalized into property values. The sacrifice in total land values can be justified only if environmental benefits are large enough. For the top 25 CBSAs, the total value of environmental benefits of open space must be at least as large as the total land value to justify for the amount of the open space they have. Some urban areas in those CBSAs likely have too much open space.

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Figure 1. U.S. CBSA and UA boundaries

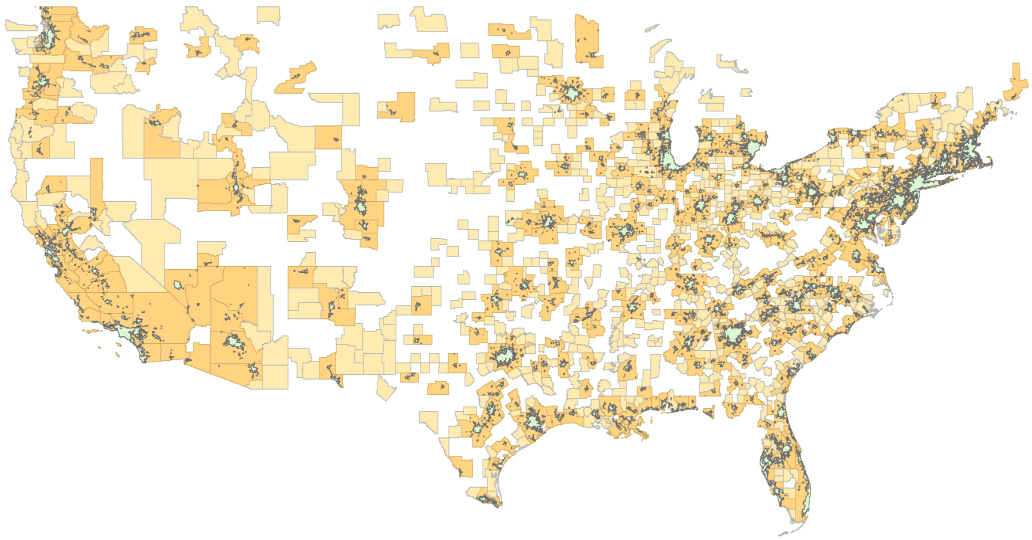
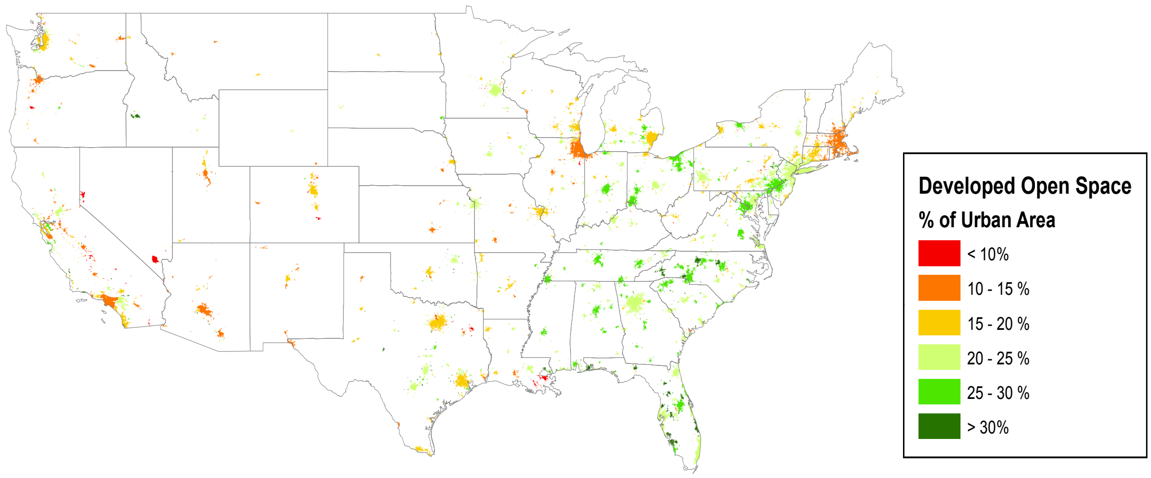
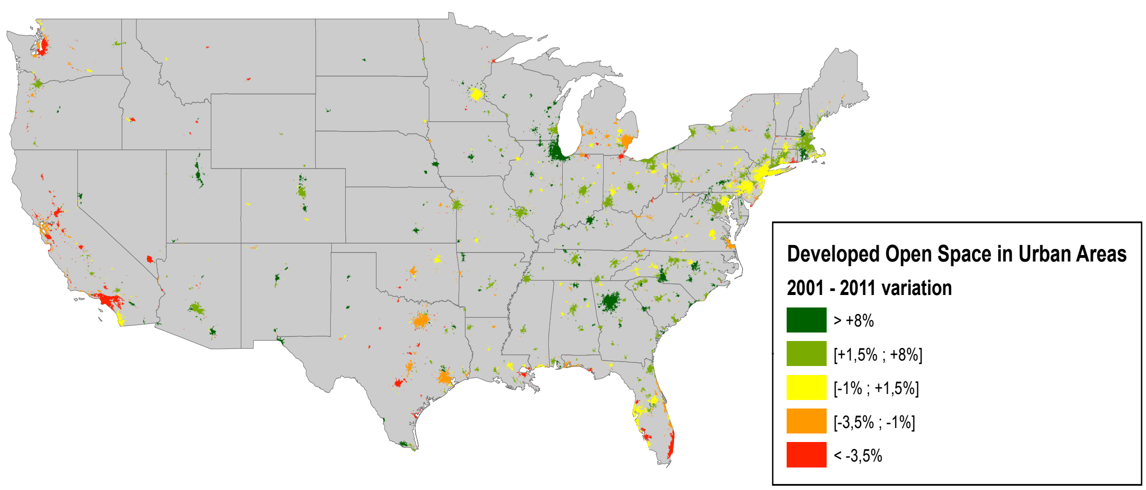


Figure 2. Developed Open Space in U.S. Urban Areas in 2011



Source: the data and map are generated using the National Land Cover Database (NLCD) created by the Multi-Resolution Land Characteristics (MRLC) Consortium.

Figure 3. Changes in the Percent of Land in Developed Open Space in U.S. Urban Areas from 2001 to 2011



Source: the data and map are generated using the National Land Cover Database (NLCD) created by the Multi-Resolution Land Characteristics (MRLC) Consortium.

Figure 4. 50 CBSAs with the highest implied values of environmental benefits relative to total land values

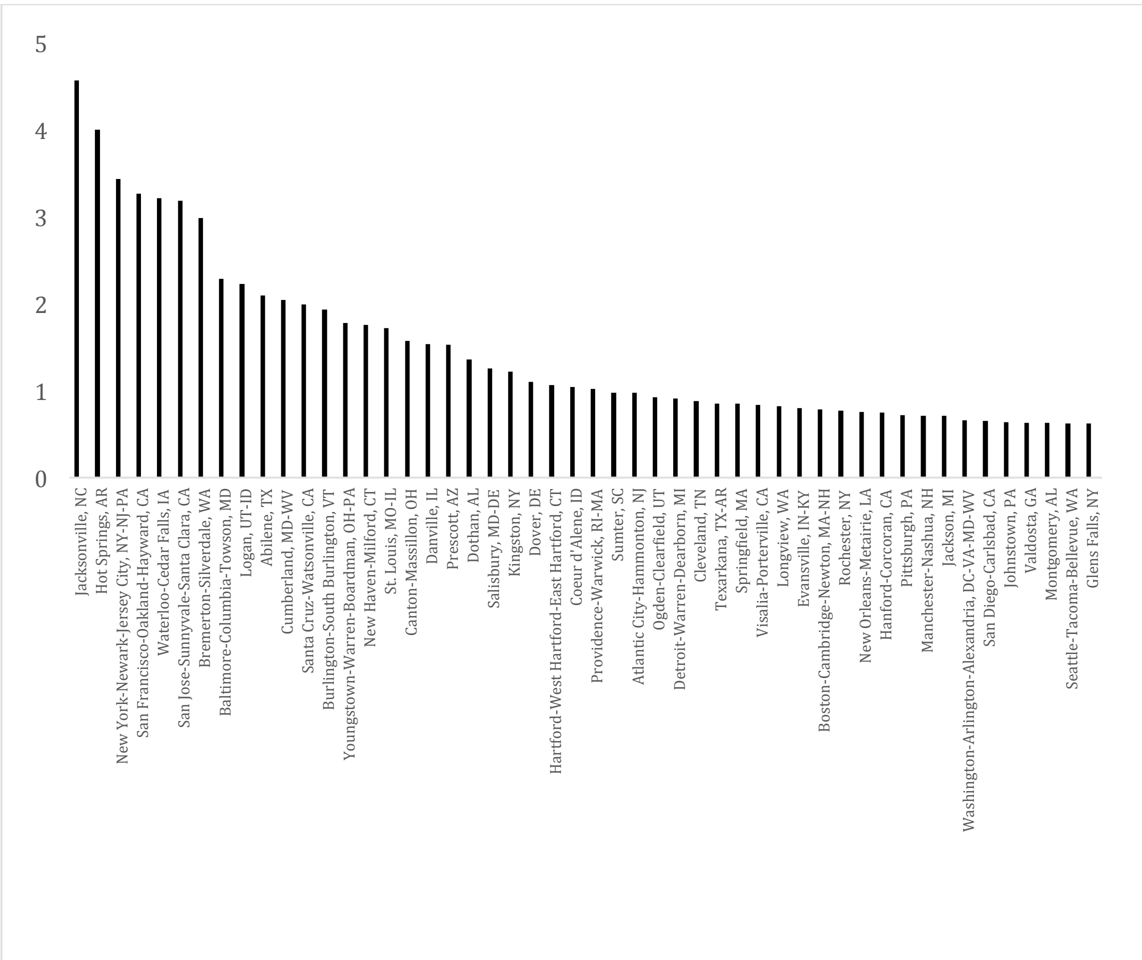


Table 1: Summary statistics for land cover of 1656 Urban Areas in the United States, in square kilometers

Types of LC	mean			sd		
	2001	2006	2011	2001	2006	2011
Open Water	3.6	3.6	3.7	18.9	18.8	19.2
Perennial Ice/Snow	0.0	0.0	0.0	0.0	0.0	0.0
Developed. Open Space	30.5	30.4	31.3	111.0	110.3	113.9
Developed. Low Intensity	32.9	36.1	34.6	120.7	131.7	126.0
Developed. Medium Intensity	19.4	21.0	23.2	88.4	95.1	100.7
Developed. High Intensity	7.5	7.6	8.9	38.1	38.7	43.3
Barren Land (Rock/Sand/Clay)	0.8	0.7	0.7	4.8	3.4	3.3
Deciduous Forest	15.5	15.0	14.1	76.7	75.6	69.0
Evergreen Forest	5.2	4.6	4.4	33.2	29.4	27.3
Mixed Forest	1.9	1.7	1.7	9.0	8.2	8.0
Shrub/Scrub	4.6	4.1	4.0	24.5	21.1	19.3
Grassland/Herbaceous	4.6	4.0	3.8	24.6	20.7	18.6
Pasture/Hay	7.6	7.0	6.2	26.3	24.0	20.6
Cultivated Crops	7.4	6.2	5.6	26.7	21.3	18.6
Woody Wetlands	5.8	5.5	5.3	30.2	27.6	27.8
Emergent Herbaceous Wetlands	1.4	1.3	1.3	8.0	7.3	7.5

Table 2. Summary statistics of housing demand and supply elasticities

Elasticities with respect to:	**Mean**	**Std**
	Log-linear demand equation	
Price	-0.92	0.79
Open Space	-0.36	4.57
Income	0.51	0.61
Public expenditure	0.63	0.99
	Linear demand equation	
Price	-0.85	0.74
Open Space	-0.21	4.45
Income	0.42	0.53
Public expenditure	0.61	1.06
	Supply equation	
Price	9.08	7.09

Table 4. Estimation results of simultaneous linear equations of property tax rate, public expenditure, and open space share

Dependent variable	Model 1			Model 2		
	Property tax rate	Public expenditure	Open space	Property tax rate	Public expenditure	Open space
Open space share	-0.000168***	-1.803**		-0.000188***	-1.569**	
	(4.58e-05)	(0.779)		(4.65e-05)	(0.768)	
Total land area	2.64e-10	-0.000857***	-4.10e-06	5.50e-10	-0.000808***	-4.62e-06
	(5.82e-09)	(0.000191)	(1.87e-05)	(5.85e-09)	(0.000186)	(1.85e-05)
Price elasticity of housing supply			0.00226***			0.00218***
			(0.000491)			(0.000490)
Price elasticity of housing demand			-0.00680			-0.0104**
			(0.00557)			(0.00505)
Elasticity of housing demand w.r.t. open space			0.000935			0.00129
			(0.000910)			(0.000879)
Elasticity of housing demand w.r.t. public expenditure	5.53e-06**	0.167***	0.000994	-2.39e-06	0.199***	-0.00584
	(2.63e-06)	(0.0390)	(0.00432)	(2.23e-06)	(0.0325)	(0.00367)
Mortgage interest rate	3.67e-07		-0.00161	7.56e-07		-0.000942
	(2.33e-06)		(0.00312)	(2.34e-06)		(0.00313)
Property insurance payment	-1.30e-07***		3.61e-05*	-1.27e-07***		3.93e-05**
	(1.43e-08)		(1.94e-05)	(1.43e-08)		(1.94e-05)
Share of open water	0.000225*		0.0810	0.000216*		0.0480
	(0.000117)		(0.160)	(0.000117)		(0.160)
Share of undeveloped land			0.595***			0.589***
			(0.0454)			(0.0455)
Number of fragmentations		8.23e-06	5.08e-06		-8.47e-06	5.45e-06
		(9.61e-05)	(9.18e-06)		(9.40e-05)	(9.06e-06)
Housing price index		0.0110***			0.00981***	
		(0.00143)			(0.00142)	
Constant	0.000343***	1.397***	0.0653**	0.000350***	1.429***	0.0635**
	(2.50e-05)	(0.332)	(0.0317)	(2.52e-05)	(0.327)	(0.0319)
Observations	753	753	753	753	753	753
R-squared	0.111	0.159	0.261	0.098	0.187	0.260

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Models 1 and 2 differ in that the demand elasticities are estimated using the log-linear demand function in model 1 and using the linear demand function in model 2.

Table 5. Estimation results of simultaneous log-linear equations of property tax rate, public expenditure, and open space share

Dependent variable	Model 3			Model4		
	log(Property tax rate)	log(Public expenditure)	log(Open space)	log(Property tax rate)	log(Public expenditure)	log(Open space)
log(open space share)	-0.145**	-0.722***		-0.169**	-0.642***	
	(0.0704)	(0.196)		(0.0711)	(0.193)	
log(total land area)	0.00178	-0.431***	0.187***	0.000372	-0.414***	0.181***
	(0.0138)	(0.0674)	(0.0412)	(0.0139)	(0.0661)	(0.0415)
Price elasticity of housing supply			0.00536***			0.00525***
			(0.00157)			(0.00158)
Price elasticity of housing demand			-0.0221			-0.0368**
			(0.0171)			(0.0158)
Elasticity of housing demand w.r.t. open space			0.000869			0.00360
			(0.00279)			(0.00273)
Elasticity of housing demand w.r.t. public Expenditure	0.0362***	0.122***	0.0178	-0.00607	0.112***	-0.00954
	(0.0131)	(0.0314)	(0.0137)	(0.0112)	(0.0259)	(0.0119)
log(mortgage interest rate)	-0.175**		-0.0750	-0.159**		-0.0594
	(0.0757)		(0.0636)	(0.0761)		(0.0644)
log(property insurance payment)	-0.630***		0.0132	-0.612***		0.0261
	(0.0534)		(0.0452)	(0.0537)		(0.0458)
log(open water share)	0.0428***		-0.000829	0.0412***		-0.00174
	(0.0110)		(0.00995)	(0.0111)		(0.0101)
log(undeveloped land share)			0.940***			0.930***
			(0.0770)			(0.0781)
log(number of fragmentations)		0.185**	-0.175***		0.170**	-0.169***
		(0.0723)	(0.0425)		(0.0707)	(0.0427)
log(housing price index)		0.643***			0.608***	
		(0.148)			(0.148)	
Constant	-4.166***	-2.470***	-0.142	-4.308***	-2.203***	-0.270
	(0.433)	(0.718)	(0.390)	(0.437)	(0.718)	(0.397)
Observations	753	753	753	753	753	753
R-squared	0.169	0.028	0.267	0.157	0.053	0.263

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Models 3 and 4 differ in that the demand elasticities are estimated using the log-linear demand function in model 3 and using the linear demand function in model 4.

Table 5. Summary of implied values of environmental benefits relative to total land values (υ) for the CBSAs where open space has a negative marginal effect on total land values

	Number of CBSAs	Mean	Std	Min	Max
Log-linear equations	217	0.59	1.71	0.00	23.23
Linear equations	211	0.50	0.93	0.00	7.82

Appendix

Table A1. Estimation results of simultaneous system of linear equations (with demographic variables)

Dependent variable	Model5. Elasticities by log-linear demand equation			Model6. Elasticities by linear demand equation		
	Property tax rate	Public expenditure	open space	Property tax rate	Public expenditure	Open space
Open space share	-0.000187***	-0.677		-0.000188***	-0.414	
	(5.29e-05)	(1.027)		(5.32e-05)	(1.015)	
Total land area	1.29e-08*	-0.000847***	2.00e-05	1.29e-08*	-0.000806***	1.53e-05
	(7.34e-09)	(0.000242)	(2.09e-05)	(7.36e-09)	(0.000239)	(2.07e-05)
Price elasticity of housing demand			0.0125*			0.00770
			(0.00653)			(0.00594)
Price elasticity of housing supply			0.00265***			0.00264***
			(0.000585)			(0.000586)
Elasticity of housing supply w.r.t. open space			0.00124			0.00110
			(0.00104)			(0.00104)
Elasticity of housing supply w.r.t. public expenditure	4.84e-06	0.155***	-0.00458	-1.34e-06	0.154***	-0.00411
	(3.15e-06)	(0.0519)	(0.00496)	(2.49e-06)	(0.0408)	(0.00411)
Mortgage interest rate	-3.59e-05***		-0.00113	-3.50e-05***		-0.00426
	(6.43e-06)		(0.00834)	(6.46e-06)		(0.00873)
Property insurance payment	-1.24e-07***		2.97e-05	-1.21e-07***		3.14e-05
	(1.52e-08)		(2.00e-05)	(1.52e-08)		(2.01e-05)
Open water share	0.000107		-0.371*	8.41e-05		-0.374*
	(0.000144)		(0.192)	(0.000144)		(0.192)
Undeveloped land share			0.629***			0.616***
			(0.0529)			(0.0530)
Number of fragmentations		-8.94e-05	6.03e-08		-0.000107	2.62e-06
		(0.000134)	(1.10e-05)		(0.000132)	(1.09e-05)
lag(income)	-1.75e-09***	3.65e-05***	-3.13e-06***	-1.65e-09***	3.48e-05***	-3.02e-06***
	(6.01e-10)	(1.04e-05)	(7.30e-07)	(6.03e-10)	(1.03e-05)	(7.32e-07)
lag(median age)	2.56e-06**	-0.0489***	0.00886***	2.79e-06***	-0.0437**	0.00869***
	(1.06e-06)	(0.0173)	(0.00122)	(1.06e-06)	(0.0170)	(0.00121)
lag(education)	-5.90e-07	-0.0301***	0.00148**	-6.14e-07	-0.0257***	0.00144**
	(5.29e-07)	(0.00864)	(0.000668)	(5.33e-07)	(0.00863)	(0.000677)
Housing price index		0.00977***			0.00876***	
		(0.00190)			(0.00191)	
Constant	0.000533***	2.232***	-0.167**	0.000519***	2.047***	-0.141*
	(5.74e-05)	(0.622)	(0.0784)	(5.72e-05)	(0.609)	(0.0793)
Observations	483	483	483	483	483	483
R-squared	0.171	0.186	0.379	0.167	0.201	0.378

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A2. Estimation results of simultaneous system of log-linear equations (with demographic variables)

Dependent variable	Model7. Elasticities by log-linear demand equation			Model8. Elasticities by linear demand equation		
	log(Property tax rate)	log(Public expenditure)	log(open space)	log(Property tax rate)	log(Public expenditure)	log(open space)
log(open space share)	-0.272***	-1.395***		-0.275***	-1.364***	
	(0.0847)	(0.415)		(0.0847)	(0.398)	
log(total land area)	0.0290	0.132	0.341***	0.0259	0.155	0.343***
	(0.0189)	(0.225)	(0.0648)	(0.0190)	(0.220)	(0.0652)
Price elasticity of housing demand			-0.0452**			-0.0402**
			(0.0189)			(0.0176)
Price elasticity of housing supply			0.00578***			0.00585***
			(0.00185)			(0.00186)
Elasticity of housing supply w.r.t. open space			0.00109			0.00307
			(0.00303)			(0.00307)
Elasticity of housing supply w.r.t. public expenditure	0.0385**	0.130***	0.00209	-0.000930	0.104***	-0.00845
	(0.0168)	(0.0426)	(0.0157)	(0.0135)	(0.0332)	(0.0132)
log(mortgage interest rate)	-1.177***		-0.0433	-1.140***		-0.120
	(0.182)		(0.134)	(0.183)		(0.140)
log(property insurance payment)	-0.640***		0.00617	-0.622***		0.0108
	(0.0648)		(0.0486)	(0.0653)		(0.0493)
log(open water share)	0.0425***		-0.0225*	0.0387***		-0.0235**
	(0.0146)		(0.0116)	(0.0148)		(0.0117)
log(undeveloped land share)			0.666***			0.653***
			(0.102)			(0.102)
log(number of fragmentations)		0.330***	-0.0587		0.329***	-0.0550
		(0.115)	(0.0506)		(0.112)	(0.0506)
lag.log(income)	-0.337**	-0.0179	-0.318***	-0.307**	-0.0603	-0.302***
	(0.135)	(0.361)	(0.103)	(0.136)	(0.357)	(0.104)
lag.log(median age)	0.300	0.469	0.844***	0.365*	0.622	0.842***
	(0.197)	(0.554)	(0.145)	(0.197)	(0.546)	(0.144)
lag.log(education)	-0.0322	-0.0544	0.129**	-0.0304	0.0358	0.131**
	(0.0688)	(0.194)	(0.0553)	(0.0700)	(0.195)	(0.0562)
lag.log(population)		-0.694***	-0.260***		-0.720***	-0.264***
		(0.256)	(0.0637)		(0.250)	(0.0639)
log(housing price index)		0.317			0.293	
		(0.209)			(0.211)	
Constant	-0.109	2.203	1.263	-0.819	2.208	1.211
	(1.448)	(3.539)	(1.210)	(1.460)	(3.483)	(1.234)
Observations	483	483	483	483	483	483
R-squared	0.177	-0.166	0.378	0.167	-0.153	0.377

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$